

Risk, Criticality and Self-Organization in Large Blackouts involving Cascading Failure

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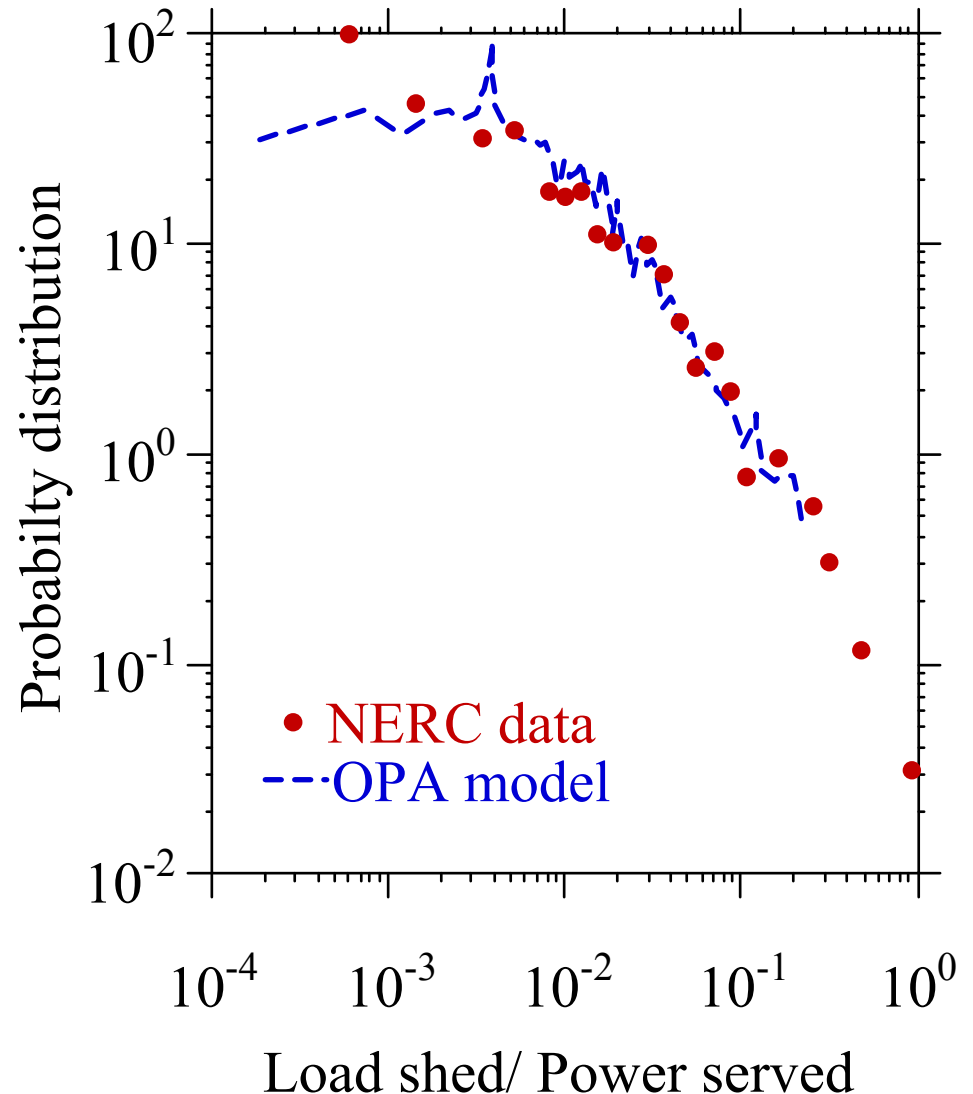
Cornell University

Transmission Reliability Research Review

U.S. Department of Energy, December 9, 2002

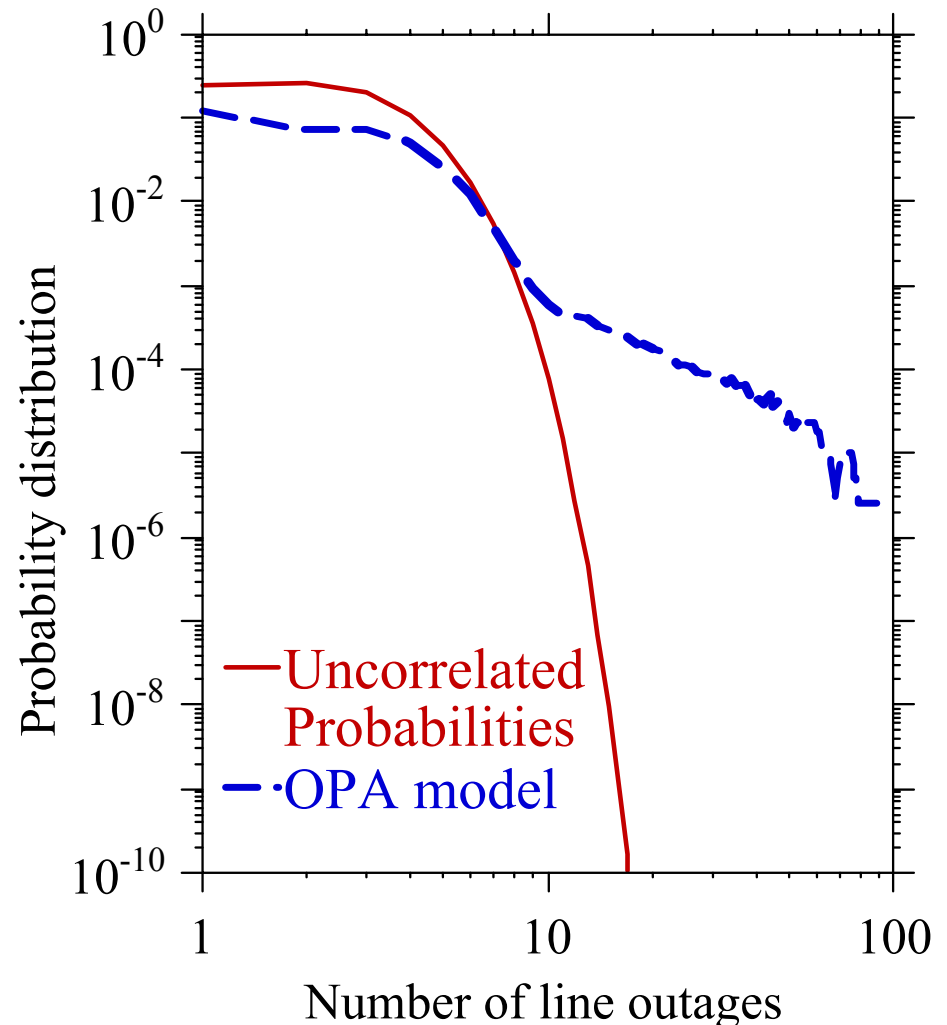
Probability of large blackouts decreases as a power of their size instead of exponentially.

- Probability distribution calculated from NERC blackout data 1984-1998: 15 years, 427 blackouts
- The power tail in pdf of the NERC data is consistent with the power system being operated near criticality



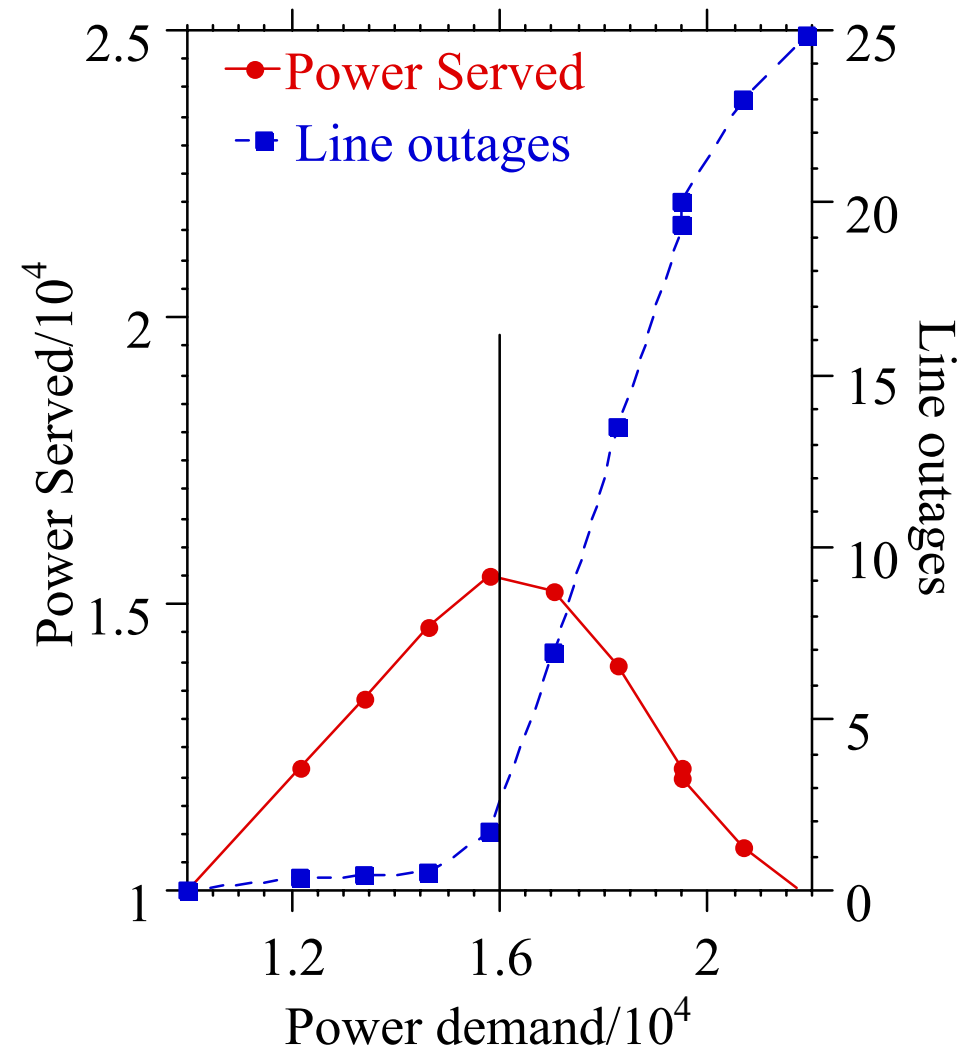
Probability of large blackouts decreases as a power of their size instead of exponentially

- Power tails imply:
 - long-range correlations
 - standard risk analysis does not apply
- We must:
 - Understand the cause of these correlations (criticality?)
 - Develop the bases for a risk evaluation
 - Be able to evaluate the impact of mitigation measures



Why would power systems operate near criticality?

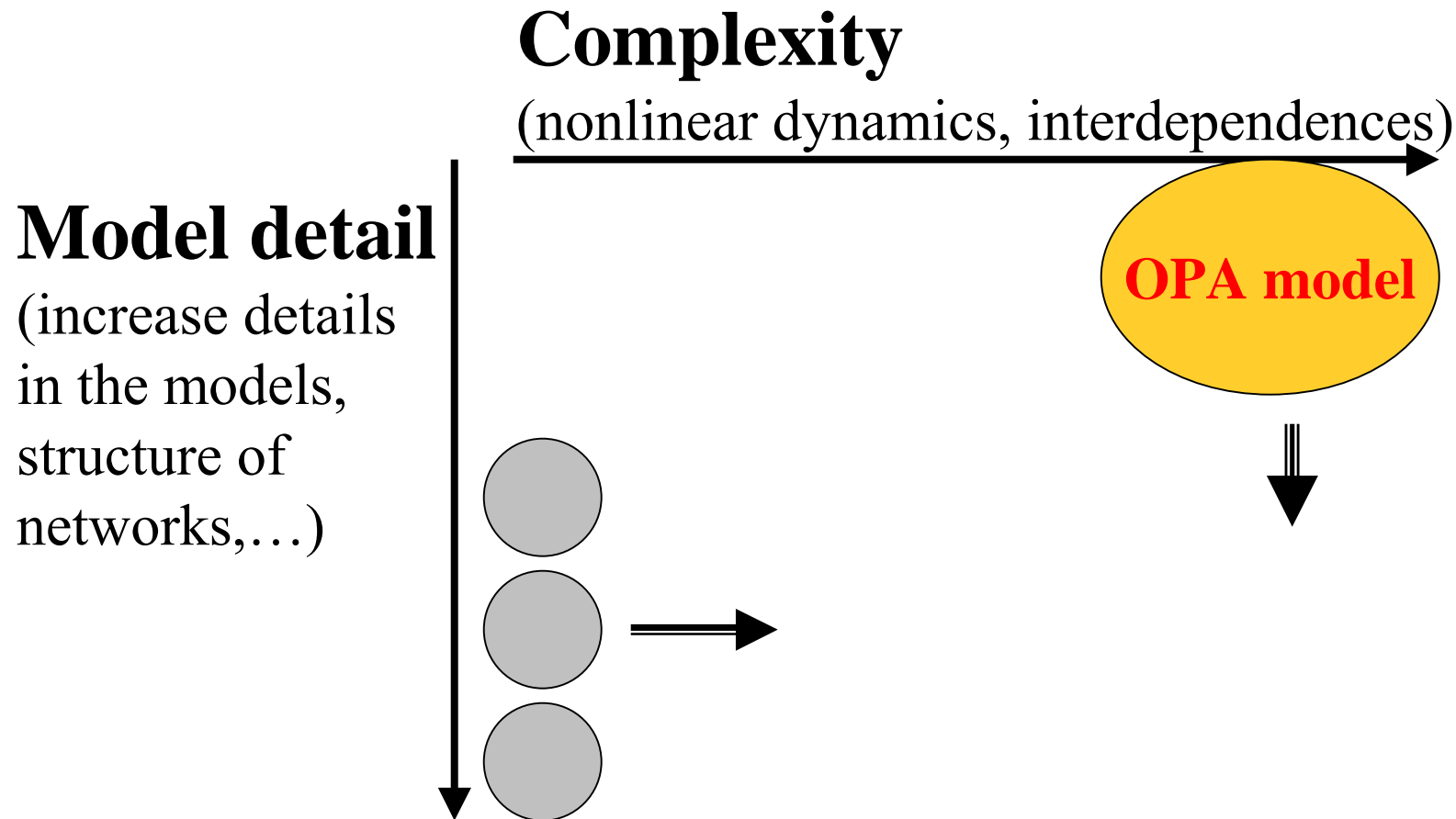
- Constant increase in power demand pushes the system toward criticality.
- Near criticality, expected blackout size sharply increases; increased risk of cascading failure.
- Load scans for different models show the appearance of power low tails (**Ian's talk**)



Blackout dynamics must include Engineering and Economic forces

- Blackout dynamics is the result of opposing forces:
 - Increase demand \Rightarrow push toward critical point.
 - Engineering response to failures
Upgrades of the transmission system
Investment in new power plants
 \Rightarrow □ □ □ □ □ □ □ the critical point.
 - Regulatory measures may set constraints in this process

Possible Approaches to Modeling Blackout Dynamics



By incorporating the complex behavior, the OPA approach aims to extract universal features (power tails,...).

OPA Model

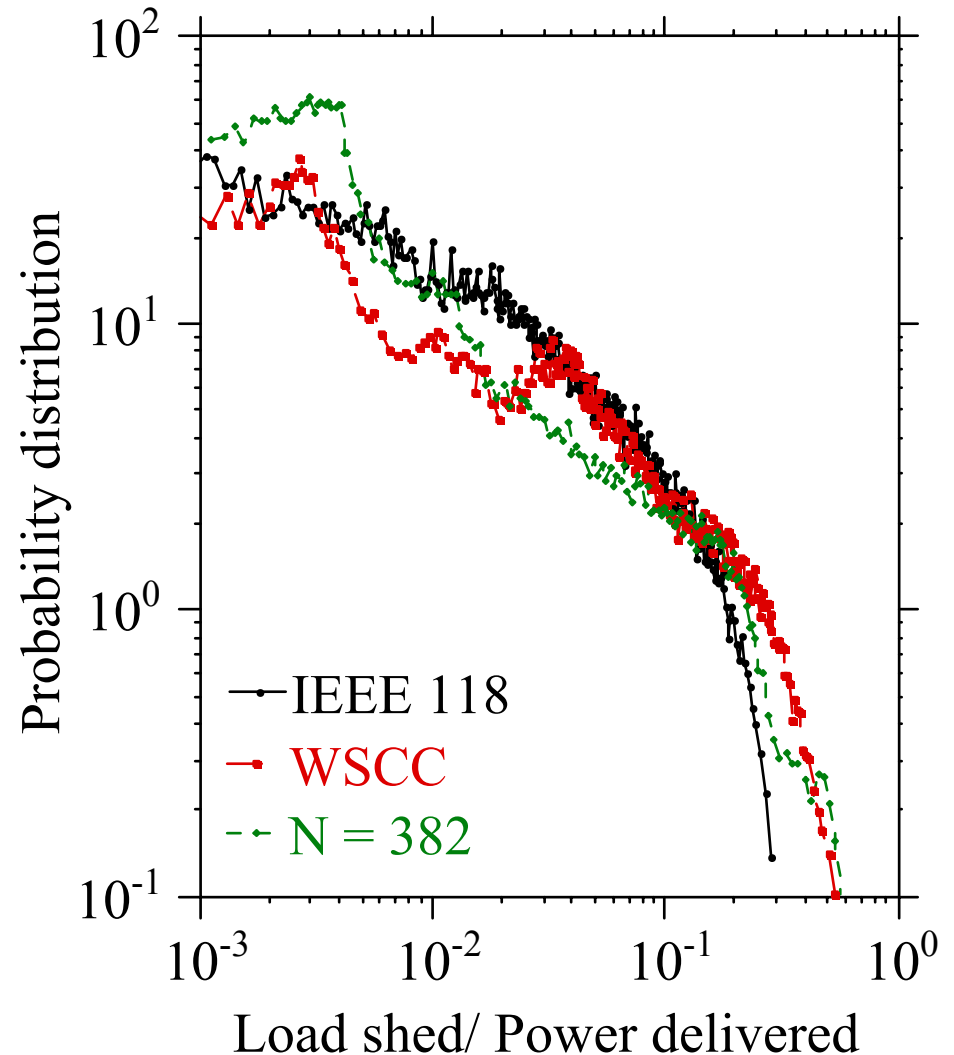
- The OPA model incorporates:
 - Transmission network model with DC load flow and LP dispatch
 - Random initial disturbances and probabilistic cascading line outages and overloads
 - Underlying load growth and load variations
 - Engineering responses to blackouts: upgrade lines involved in blackouts;
 - Upgrade generation in response to increase demand
- Each of these components is expected to evolve over time by increasing the level of detail of the models.

Recent Results

- Completed the FY2002 tasks.
- Main results:
 - Developed a module for the upgrading the generator power in response to the increase demand.
 - Application of the OPA model to IEEE 118 bus and WSCC network configurations.
 - Development of the CASCADE model (**Ian's talk**)
- Work in progress:
 - Formulation of a risk analysis approach
 - Assessment of blackout mitigation measures.

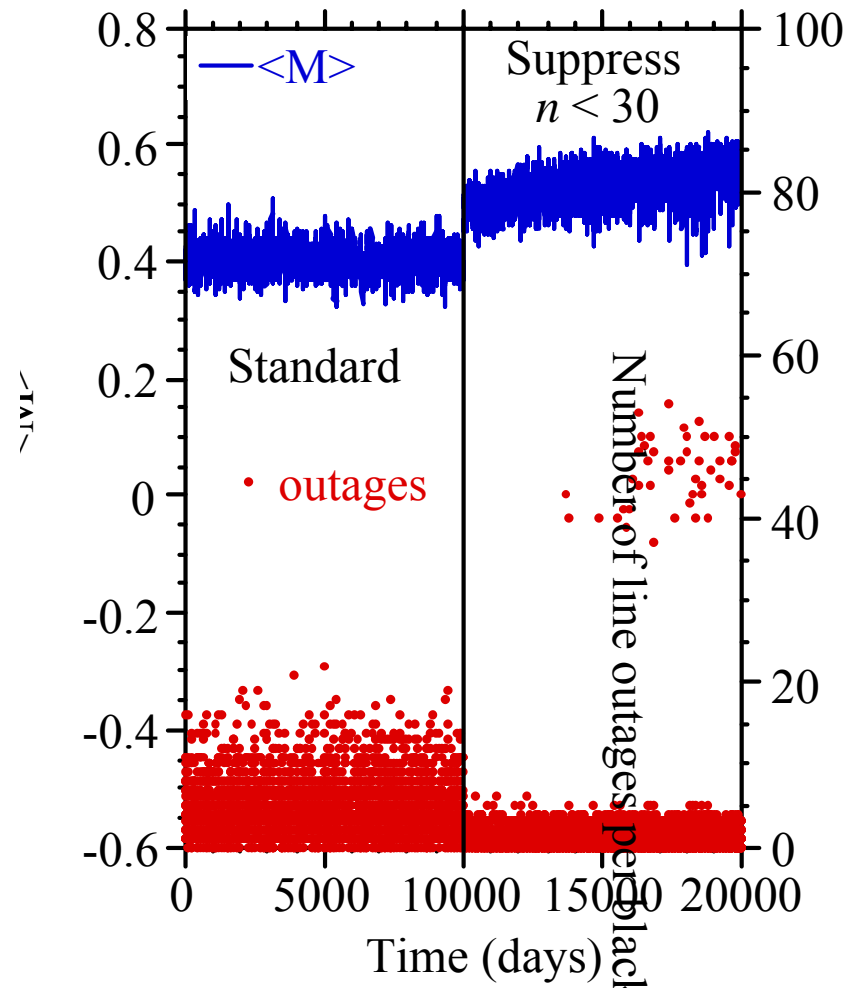
Application of the OPA model

- The probability distribution function of blackout size for different networks has a similar functional form.
- Similar functional forms can also be obtained from analytical modeling (**Ian's talk**)
- Universality of the probability distribution function?



Dynamics is Essential in Evaluating Mitigation Measures

- Suppose power system organizes itself to near criticality
- We try a mitigation method requiring 30 lines to overload before outages occur.
- The measure is effective over a relative short time scale. In a long time scale very large blackouts occur.



Two main ideas towards the next steps in this project

- Functional form of the probability distribution function of the blackouts is universal:
 - Develop an analytical model (CASCADE model) to better determine this functional form (**Ian's talk**)
 - Develop a Risk analysis approach based on this pdf
 - Increase the level of detail and realism of the components of the OPA model to test the universality of the results.
- Need to use dynamical models to determine the impact of mitigation measure in the system

Risk, Criticality and Self-Organization in Large Blackouts involving Cascading Failure Part II

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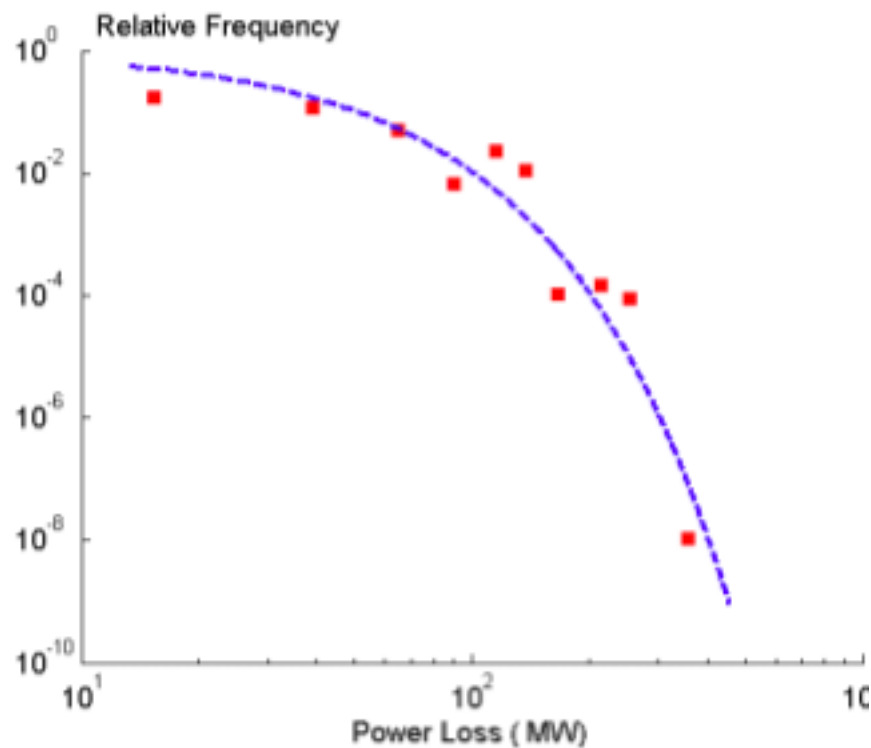
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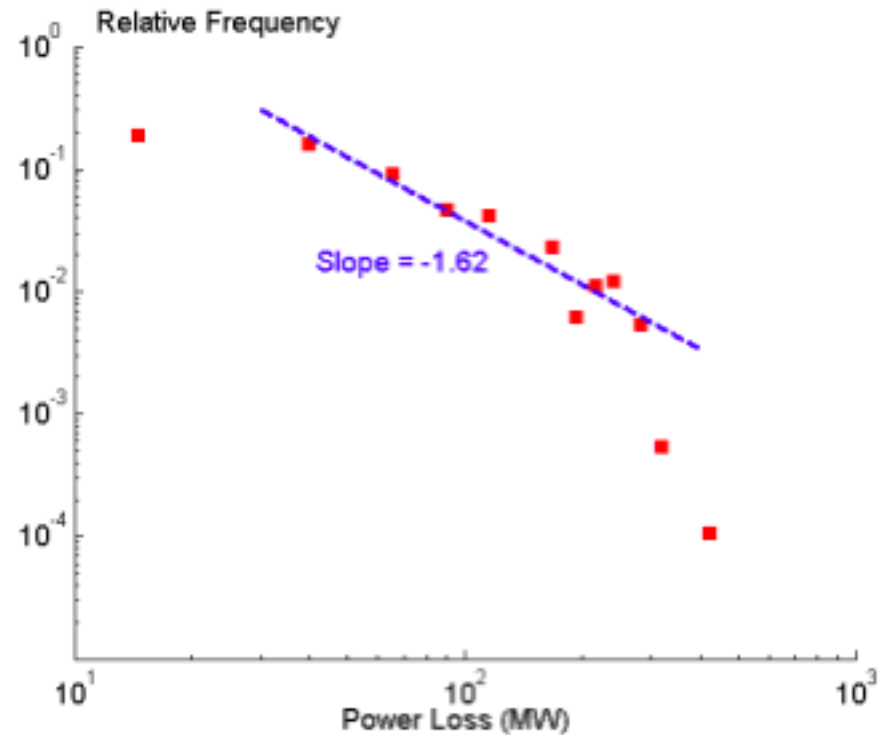
Hidden Failure Model

- Transmission network model with DC load flow and LP dispatch
- Random initial line trip
- Represents hidden failures of relay system: exposed lines trip randomly depending on loading
- Overloaded lines trip
- Importance sampling to make rare event simulation practical

Power law tails near criticality



loading below critical

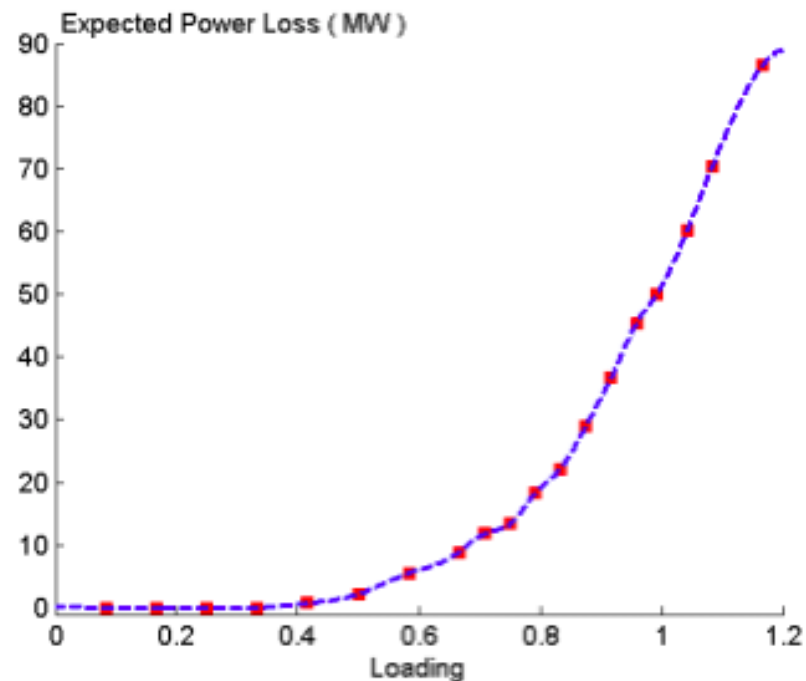


loading near critical

probability distribution of blackout size

Load scan and criticality

- Near criticality, expected blackout size sharply increases; increased risk of cascading failure.
- Power law tails at criticality
- Where is the “edge” for cascading failure?

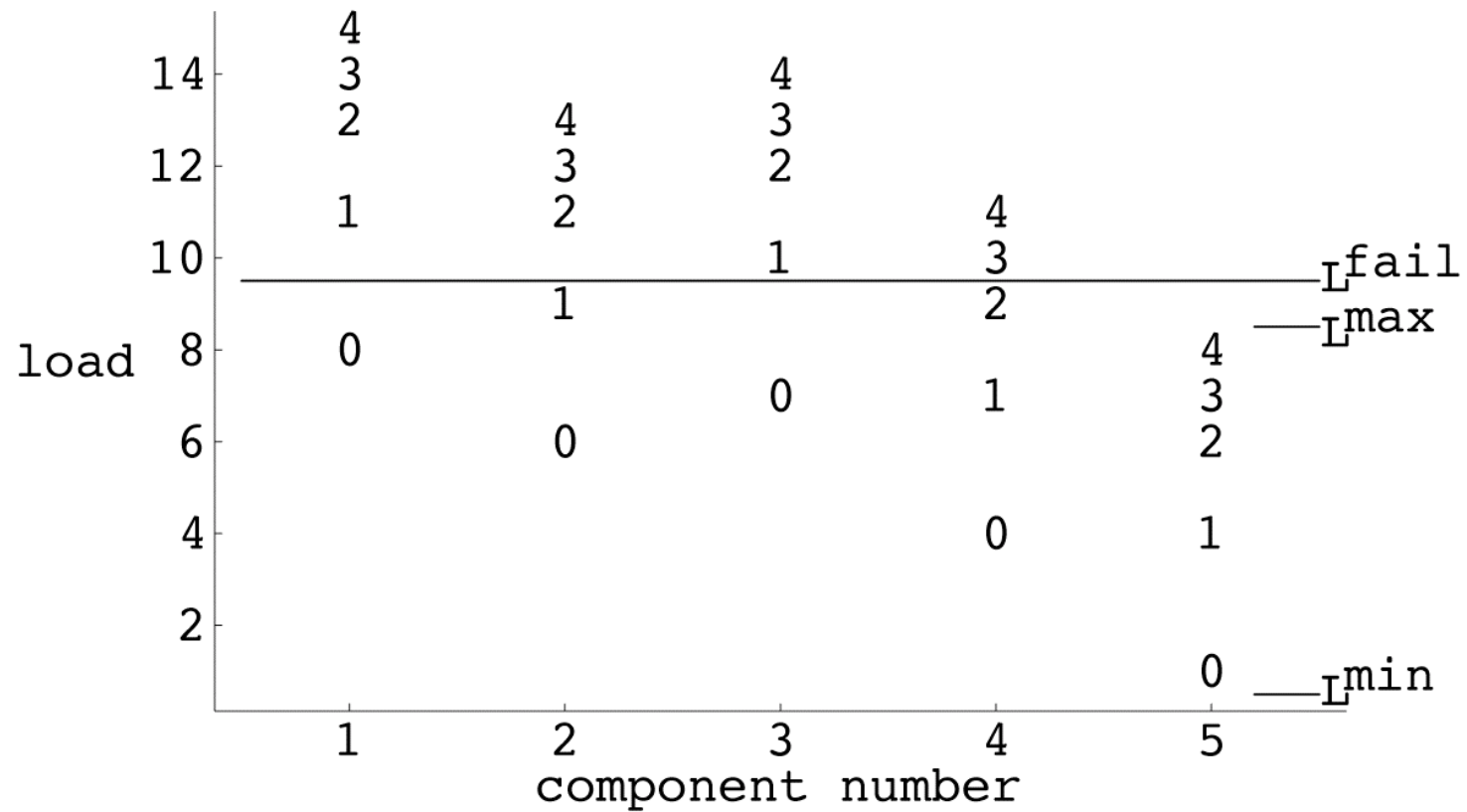


expected blackout size versus loading
hidden failure model

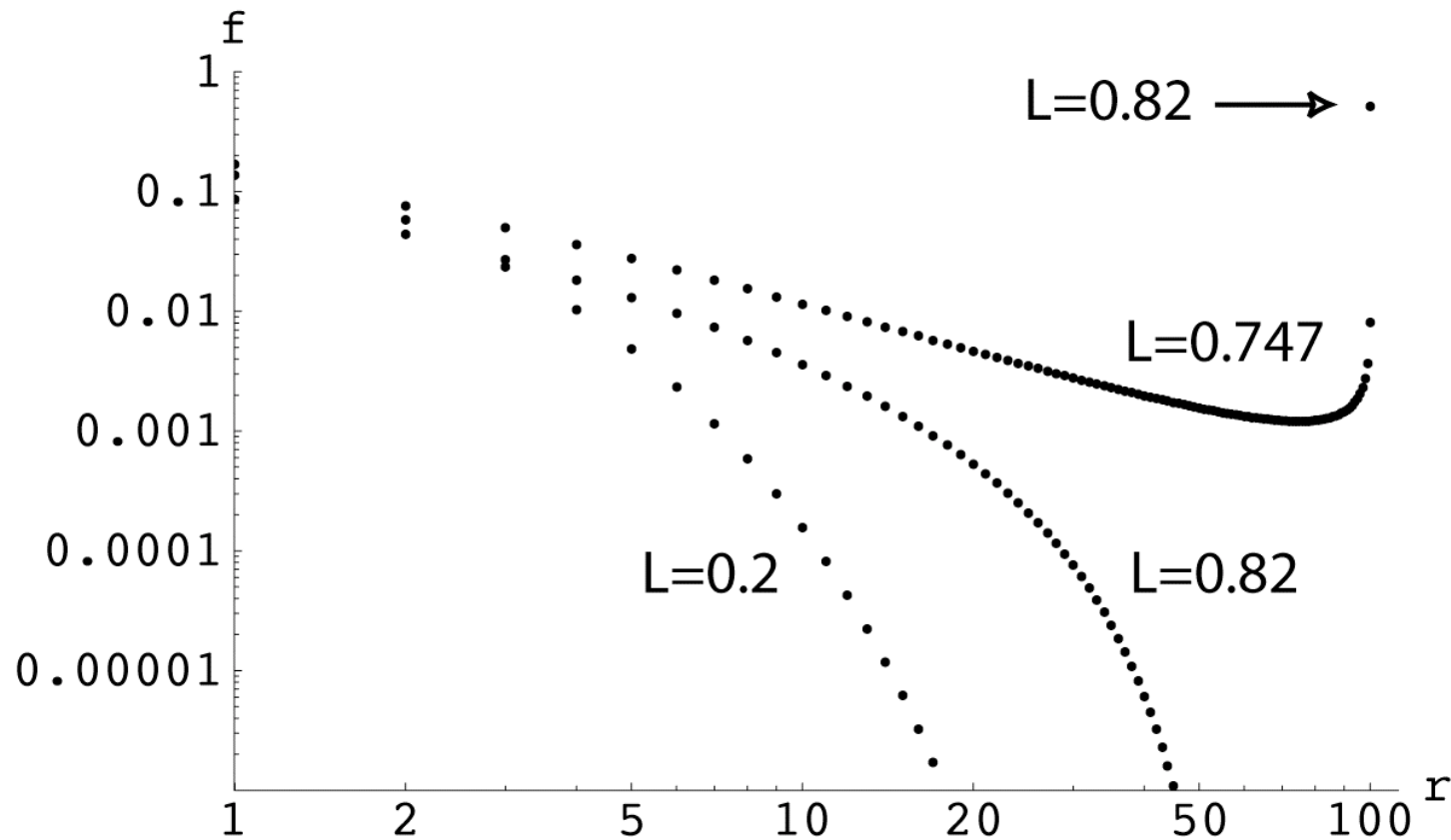
CASCADE Model

- Loading-dependent probabilistic cascading failure
 - identical components with random initial loads
 - initial disturbance to start cascade
 - when load exceeds threshold, component fails and transfers load to all other components
- Formula for probability distribution of number of failed components
- Objective: learn about cascading failure

5 component example



probability distribution as average load L increases



Project Progress

- Deliverables
 - Draft final report written; to be finalized in January
 - 5 conference papers
 - Journal paper in CHAOS
- Work in progress:
 - Formulation of a risk analysis approach
 - Assessment of blackout mitigation measures
 - Testing universality of results with OPA
 - Using CASCADE to understand cascading failure.

Papers

Dynamics, criticality and self-organization in a model for blackouts in power transmission systems, Carreras, Lynch, Dobson, Newman. HICSS 2002.

Examining criticality of blackouts in power system models with cascading events, Dobson, Chen, Thorp, Carreras, Newman, HICSS 2002.

An initial complex systems analysis of the risks of blackouts in power transmission systems, Dobson, Newman, Carreras, Lynch, CRIS conference, Beijing 2002.

Blackout mitigation assessment in power transmission systems, Carreras, Lynch, Newman, Dobson, HICSS January 2003.

A probabilistic loading-dependent model of cascading failure and possible implications for blackouts, Dobson, Carreras, Newman, HICSS January 2003.

Evidence for self-organized criticality in a time series of electric power system blackouts, Carreras, Newman, Dobson, Poole, SUBMITTED to IEEE Trans CAS.

Critical points and transitions in an electric power transmission model for cascading failure blackouts, Carreras, Lynch, Dobson, Newman, CHAOS 2002.
---- led to story in NATURE SCIENCE NEWS, November 2002

Challenges

- Risk analysis and blackout mitigation based on entire pdf, including high risk large blackouts.
- Understand and avoid cascading failure due to interacting rare events:
where is the “edge” for high risk of cascading failure?